Pilot Carrier Frequency Standard

By Luther M. Stroud

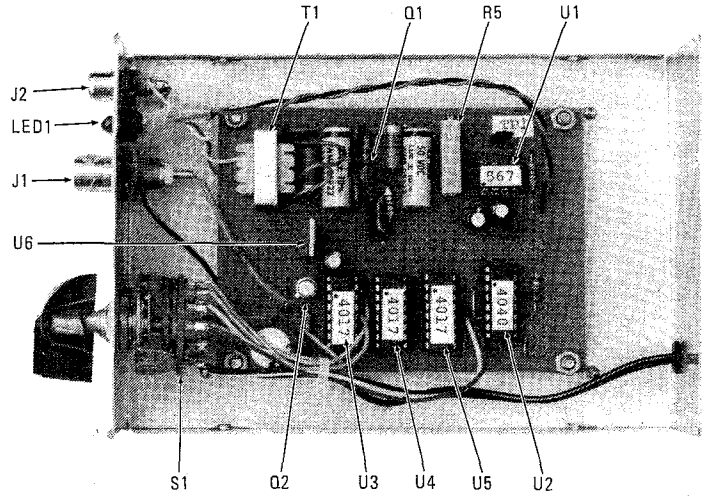
This project turns most any FM monaural radio into an accurate signal source for experimenting or calibrating.

AS AN ELECTRONICS ENTHUSIAST OR TECHNICIAN, IN AN ERA of high-performance digital equipment, surely you've had need of a calibrated signal source to check the accuracy of some piece of test equipment, or a stable clock source for experimental purposes. Of the hundreds of circuits that have been published for low-frequency squarewave oscillators, almost all of them suffer from thermal drift and instability due to changes in power-supply voltage.

Crystal oscillators offer a vast improvement in stability, but they work at only one frequency. That means, to use such a circuit in any meaningful way, you must first obtain a crystal and build an oscillator circuit to make it work. Then, once it's working, you must laboriously hook up decade counter/dividers to divide the frequency down to something more useful. And the problem is further compounded by the circuit in which the crystal is used.

The crystal manufacturer may specify the accuracy to be within ± .005%; but, the crystal may behave differently in your circuit. So unless the output frequency is measured with test equipment of known accuracy, you will never really know exactly what you're getting. And that's where our little project comes in: To those who don't have access to expensive equipment to measure and trim an oscillator to exact frequency, this project offers an inexpensive alternative. It borrows accuracy from another source—namely, the stereo pilot carrier (broadcast at low amplitude in the stereo program) from any local FM-stereo radio station.

When an FM radio station broadcasts in stereo, the low-amplitude pilot carrier is used by the multiplex decoder in a stereo receiver to recreate the right and left channel audio and turn on the stereo indicator. But in a monaural radio, the stereo pilot is not used (there's no separation of left and right channel signals), therefore both signals are delivered to one speaker. The FCC specifies the pilot carrier to be 19 kHz ± 2 Hz, which translates to ±.001%—a rather tight tolerance. In fact, the measurements that I made of the pilot with a lab-grade frequency counter showed that most stations were ± .00015% of that 19 kHz signal. Let us now look into how this project makes use of that accurate signal by converting it to something more useful.



The design of the project is simple enough for perfboard construction. Following the author's layout is highly recommended, even if you decide to go the printed-circuit route. Because of the high gain of U1, lead length should be kept short to minimize noise pickup.

About the Circuit

Refer to Fig. 1, the schematic diagram of

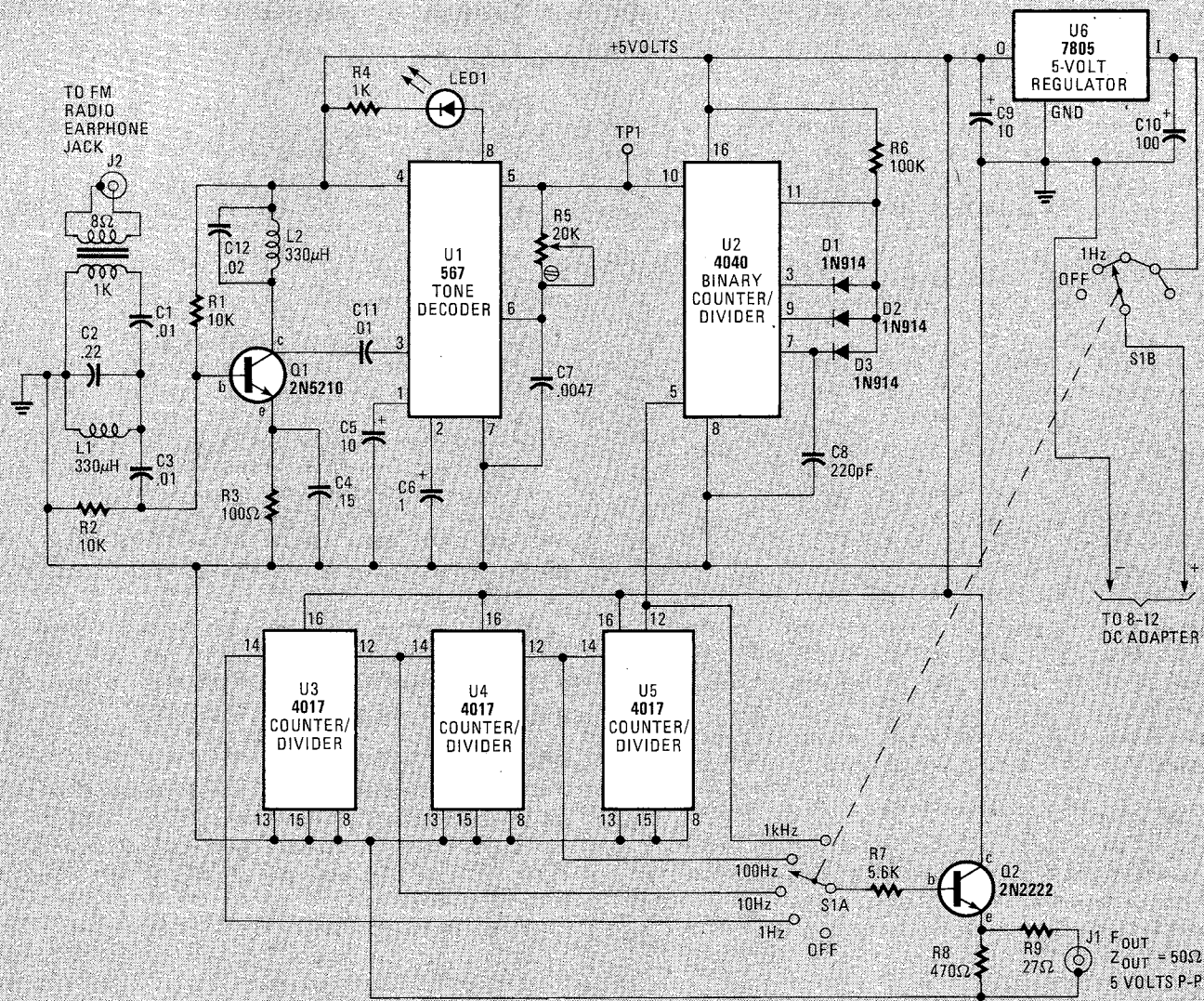


Fig. 1—Audio from the earphone jack of an inexpensive monaural FM portable radio is coupled through T1—an audio transformer, which provides isolation and impedance matching—to the filter stages of the circuit, which strips the carrier (using two tuned parallel-resonate tank circuits) from FM stereo broadcasts.

the circuit that extracts the carrier from FM broadcasts. Audio from the earphone jack of an inexpensive monaural FM portable radio is coupled through T1—an audio transformer, which provides isolation and impedance matching—to the first filter stage. A parallel resonate tank circuit, formed by C2 and L1, tuned to 19 kHz sharply attenuates all signals except the 19 kHz pilot signal.

The remaining signal, a combination of a 19-kHz sinewave and high-frequency program audio, is coupled by C3 to an active filter—a class "A" amplifier, consisting of Q1, R1, R2, and R3. Another tank circuit, formed by C12 and L2, and also tuned to 19 kHz, is placed in the collector circuit of Q1. C4 bypasses R3 to prevent degenerative feedback. The amplifier's gain is highest at the 19 kHz resonant frequency due to the tank circuit.

The tank circuit should provide about 50 millivolts of output with distortion and noise, which is then sent via C11 to the input of the 567 tone decoder—a special-purpose device intended primarily to tell logic circuits when a signal tone is present at its input. A typical application would be to detect when a button of a touch-tone phone is pressed.

The chip, which has high gain and good noise immunity, is capable of detecting a 40-millivolt signal in very heavy noise, provided that the signal is within its detection band. High level signals (above 200 millivolt) tend to cause some instability. The device is useable at frequencies of from 0.1 to 500 kHz.

The voltage-controlled oscillator's center frequency is set to operate at 19 kHz with values specified for R5 and C7. C5 and C6 set up the band-width and damping of the PLL. R4 and LED 1 form an indicator circuit to let you know that the PLL is locked onto the incoming signal.

At Pin 5, a squarewave signal of 5-volts peak-to-peak is generated at a 90-degree phase angle to the incoming signal when locked. At Pin 4 a regulated 5 volt power supply is used because the VCO center frequency is somewhat affected by power supply variations.

The 19-kHz squarewave is applied to the input of a binary ripple counter (U2). D1, D2, D3 and R6 form a 3-input AND gate that resets U2 every 19 counts, making it work as a divide-by-N counter. C8 helps to widen the reset pulse and may not be needed in some cases. The output of U2 at pin 5 (a

PARTS LIST FOR THE PILOT CARRIER FREQUENCY STANDARD

SEMICONDUCTORS
D1–D3—1N914 general-purpose, small signal, silicon diodes
LED1—Jumbo red light-emitting diode
Q1—2N5210 NPN silicon transistor
Q2—2N2222 NPN general-purpose, silicon transistor
U1—567 tone decoder, integrated circuit
U2—4040 ripple-carry, binary counter/divider, integrated circuit
U3–U5—4017 decade counter/divider, integrated circuit
U6—7805 5-volt, 1-A voltage regulator, integrated circuit

RESISTORS
(All resistors are ¼-watt, 5% fixed units, unless otherwise noted.)
R1, R2—10,000-ohm
R3—100-ohm
R4—1000-ohm
R5—1000-ohm, multi-turn potentiometer
R6—100,000-ohm
R7—5600-ohm
R8—470-ohm
R9—27-ohm

CAPACITORS
C1, C3, C11—0.01-μF, ceramic disc
C2, C12—0.02-μF, 50-WVDC Mylar
C4—0.15-μF, 50-WVDC, Mylar
C5, C9—10-μF, 16-WVDC, electrolytic
C6—1-μF, 16-WVDC, electrolytic
C7—0.0047-μF, 50-WVDC, Mylar
C8—220-pF, ceramic disc
C10—100-μF, 25-WVDC, electrolytic

ADDITIONAL PARTS AND MATERIALS
J1—BNC-type, female panel-mount connector
J2—RCA-type female phono jack
L1, L2—330-μH, RF choke
S1—Double-pole, 6-position, rotary switch
T1—Audio transformer, 8-ohm to 1000-ohm (Radio Shack #273-1380 or similar)
Printed-circuit or perfboard material, enclosure, 8- to 12-volt plug-in DC power supply, hardware, wire, solder, knobs, etc.

1 kHz nearly symmetrical squarewave) is sent to 3 additional decade counters, which further divide the 1 khz output of U2 to provide 100 Hz, 10 Hz, and 1 Hz signals. S1 selects the output frequency to be fed to buffer Q1 (configured as an emitter follower). R7, R8, and R9 set the output impedance to 50 ohms with a 5-volt peak-to-peak level.

Construction

The design of the project is simple enough for perfboard construction, and following the author's layout (see photos) is highly recommended. Due to the high gain of U1, lead length should be kept short to minimize noise pickup. A 5-volt regulated and well filtered power source is also needed for best stability of the circuit.

A 9-volt battery might be used for a power source. But, since the circuit draws about 35 mA, a plug-in DC power supply capable of supplying 9- to 12-volts with a current capacity of at least 50 mA is recommended and is less costly for extensive use. The positive power-source wiring to S1 should be double-checked before power is applied to the the circuit to insure that the proper pole is being used. A wiring mistake there could destroy the chips.

The value of C8 is not critical—any value between 100 and 470 pF is just fine. When wiring LED1, the lead nearest the flattened side (cathode) goes to R4. A template of the front panel layout is provided in Fig. 2, which can be copied or cut from the page and affixed to the front panel, with some clear plastic laminating film covering the panel to protect the paper's surface and enhance the appearance.

Check Out and Use

Take a moment to look over your handiwork. Are the diodes and electrolytic capacitors polarized correctly? Are the red and white wires from T1 going to the audio input jack? Have the chips been correctly oriented in their respective sockets? If so, proceed.

Set R5 to mechanical center and apply power. LED1 should light up momentarily. Tune an FM portable radio to a local station broadcasting in stereo. Apply audio to the project from the radio's earphone jack using a suitable cable. Advance the volume control about halfway, and if there is a tone control, set it to maximum treble. LED 1 should light, indicating your project is locked onto the stereo pilot carrier.

The adjustment of R5 can be optimized by reducing the radio volume and readjusting R5 to lock in the circuit with a minimal audio level. A small speaker can be connected to the output to test for the presence of proper signals. The above adjustments can be made with no special equipment, but if you are purist and have access to test equipment, do the following. Without audio applied, connect a scope to the project's output and select the 1000 position.

Adjust R5 for a period of 1 millisecond: 1 kHz if you are using a frequency counter. Doing things in that manner is preferred over monitoring TP1 for 19 kHz, because TP1 is a rather high-impedance point and even a ×10 probe will cause a shift in the center frequency. When audio is applied and the PLL locks, the output will be as accurate as the pilot carrier.

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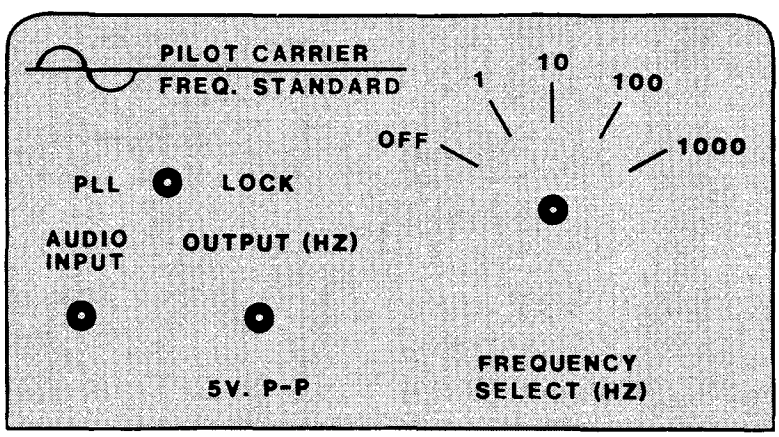

Fig. 2—This front-panel template can be copied or cut from the page and affixed to the front panel, with clear plastic laminating film covering the paper's surface to protect the project and enhance its appearance.

BUILD THE VOX BOX

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IC's. No provision is made to mount the override switch S1 on the circuit board. Should you decide that it is needed for your application, mount it on the box. Since the project is very light, use a toggle switch and not a slide switch—the former will be easier to operate with one finger.

The terminal pins are numbered from 1 to 10 in the schematic diagrams (Figs. 1 and 4) and the parts-placement diagram (Fig.3). They are listed with their related circuit connections in Table 1.

Before the Test Flight

Check your work very carefully as you follow through to completion of the project. In particular, check the polarity and pin placement of the IC's, transistor, diodes, and electrolytic capacitors by comparing your work to Fig. 3.

If the VOX Box is to be controlled by signals with an amplitude of 100 millivolts or more, there is no need for the microphone preamplifier stage. Just omit all the components to the left of C4 *except* for resistors R2 and R3, and capacitor C2. Refer to the details given in Fig. 4. The impedance of the audio-signal source used as an input in Fig. 4 must be less than 5000 ohms. That output impedance is typical of many cassette and tape decks.

The threshold potentiometer, R8, may be replaced with a panel-mounting volume control of the same rating should you want to *spiff* up the VOX Box's appearance and utility.

To test VOX Box, connect the microphone and power supply, and set the R8 threshold control to maximum sensitivity. Connect an oscilloscope to the MIC OUTPUT and check the hum level in the event the preamplifier (U1) is used. Vary the setting of the GAIN control (R6) at high levels of amplification. If the hum is excessive, check the filtering capacity of the power supply. You may need 100-μF, or more to kill the ripple in the AC line-operated, power supply. If that doesn't work, then you must resort to a metallic enclosure. The VOX Box circuit should be grounded only at the microphone-input ground return.

Adjusting the two controls on the VOX Box is a simple procedure. The GAIN control (R6) is set to obtain the desired signal level at the MIC OUTPUT pin, while THRESHOLD control R8 is adjusted to provide reliable triggering. If you wire the circuit in Fig. 4 (not using the microphone output), set R8 to its mid-setting (50,000-ohms) and adjust R6 for reliable triggering.

Transistor battery operation is only possible for limited periods, because of the circuit's large current drain when the relay coil draws current. I used a transistor-radio battery during the test procedure and found that it provided sufficient power for about half an hour until I shut it down. How long will it operate under that type of power supply? It depends on the relay used and the total period it is on. Why not try it out and determine whether or not the VOX Box can be powered from a battery for the time intervals that you plan to use it. ■

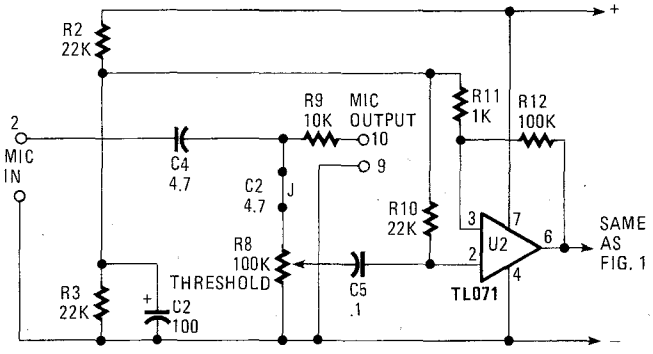

Fig. 4—Here is the revised partial schematic diagram of the unit with the preamplifier section omitted as described in text.

PILOT CARRIER

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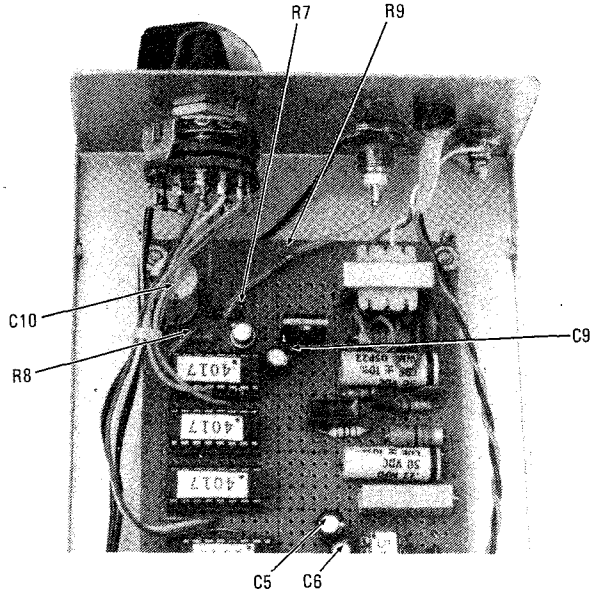
The project can now be used to calibrate an oscilloscope's timebase or check a counter's accuracy. If a 1 or 10 MHz oscillator is divided down to 1 kHz, it can be calibrated by comparing the two squarewave signals on a dual-trace scope. Simply adjust the trimmer capacitor for zero beat.

Let's take a moment to ponder some other uses for the project. Try replacing T1 with a magnetic telephone recording pickup and increase the values of C2, C12, and C7 to allow operation at 15 kHz. That provides access to another accurate signal source, your TV set. Place the pickup near the back of the TV to couple into the flyback transformer's magnetic field. The project will now lock onto the horizontal sync frequency broadcast by the TV station.

If the TV is tuned to a network originated program, the frequency is exactly 15734.265 Hz. All three networks use a rubidium atomic oscillator of 5 MHz from which all of the sync signals are derived. That master oscillator is compared and corrected to the National Bureau of Standards (NBS) in Boulder, Colorado.

Radio WWVB is broadcast by NBS at 60 kHz ± 0.00001 Hz. Maybe you can use the project with a suitable antenna and preamp to decode their signal. Some experimenting and modifications of the project will be necessary to use that signal. ■



In the author's prototype, resistor R9 is not mounted to the perfboard, instead, one lead is soldered directly to J1's center (signal carrying) terminal—with its leads insulated from other components by tubing—and the other lead is connected to the junction formed by Q2 and R8.